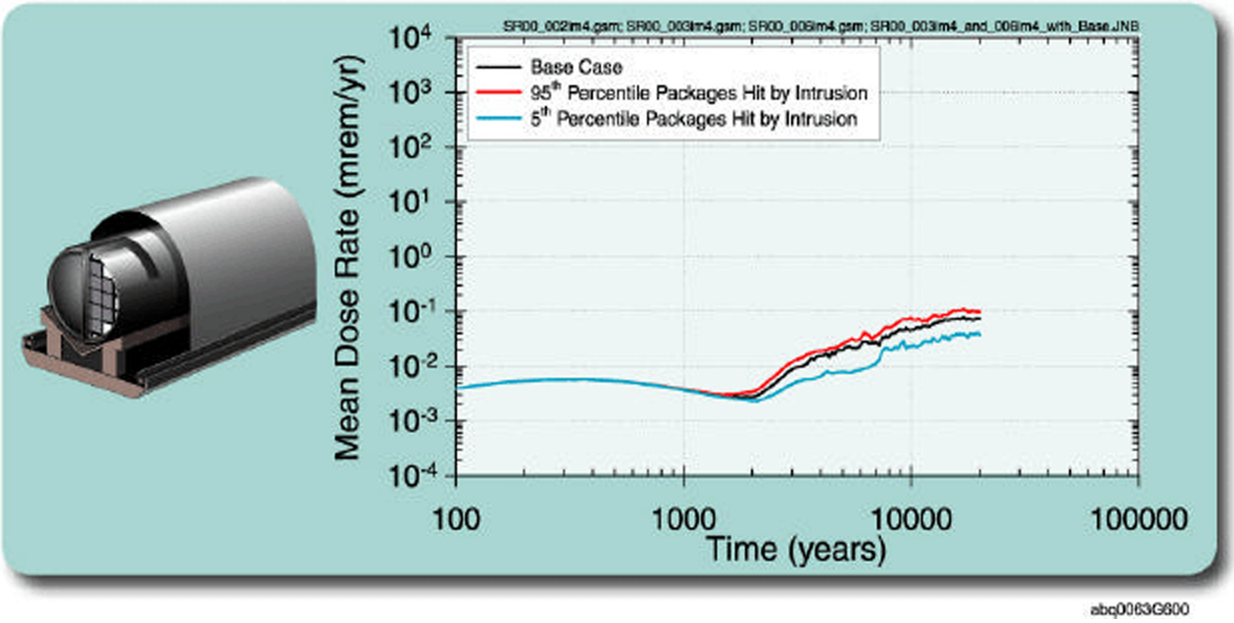

Figure 4-37. Sensitivity to the Number of Waste Packages Hit During an Intrusive Igneous Event (From CRWMS M&O, Page F5-46) (1.0 mrem/yr = 0.01 mSv/yr)

4.3.11 Airborne Transport of Radionuclides (DIRECT2)

Risk Insights:	
Volume of Ash Produced by an Eruption	Medium Significance
Remobilization of Ash Deposits	Medium Significance
Inhalation of Resuspended Volcanic Ash	High Significance
Wind Vectors During an Eruption	Medium Significance

4.3.11.1 Discussion of the Risk Insights

Volume of Ash Produced by an Eruption: Medium Significance to Waste Isolation

The concentration of radionuclides in ash is affected by the volume of ash released during an igneous event. Relative to small-volume eruptions, larger-volume eruptions dilute the concentration of high-level waste in the volcanic deposit.

<u>Discussion</u>

Basaltic volcanoes in the Yucca Mountain region have many characteristics of basaltic cinder cones that have erupted with historical observations. Although most eruption deposits from volcanoes in the Yucca Mountain region are poorly preserved, sufficient information exists to conclude that the range of past activity at these volcanoes is analogous to that observed at historical eruptions (e.g., Connor, 1993; NRC, 1999). Comparison of Yucca Mountain basaltic volcanoes to historical volcanoes with magmatic water contents of at least 2 wt % shows the ubiquity of an eruption plume that deposits tephra for tens of kilometers away from the vent

(e.g., NRC, 1999). Erosion has removed most of the tephra-plume deposits from Yucca Mountain volcanoes; thus, these volumes need to be estimated. NRC (1999) used deposit ratios from well-characterized historical eruptions to estimate volumes of tephra deposits for Yucca Mountain volcanoes, with a similar approach adopted in CRWMS M&O (2000b).

The current TPA Version 4.1 code uses a relationship between eruption power and duration to calculate ash volume during an eruption. The power and duration ranges used to represent potential igneous events correspond to estimated ash-volume ranges of 6×10^5 to 3×10^8 m^3 [2×10^7 to 1×10^{10} ft^3], with an average volume of 3×10^7 m^3 [1×10^9 ft^3]. For comparison, the ash volume for Lathrop Wells volcano is estimated at 5×10^7 m^3 [2×10^9 ft^3] (NRC, 1999). DOE currently uses a range of ash volumes from 2×10^6 to 4.4×10^8 m^3 [7×10^7 to 2×10^{10} ft^3], with an average volume of 1×10^8 m^3 [4×10^9 ft^3]. The effect of these different volume ranges is shown in Figure 4-38. In this analysis, a factor of 2 increase in average ash volume resulted in a factor of 3 decrease in average conditional dose (i.e., dose not weighted by the probability of scenario occurrence).

Uncertainties

Because most of the ash deposits have been eroded from old volcanoes in the Yucca Mountain region, ash volumes for these volcanoes are uncertain. Ash-to-cone volume ratios at historical

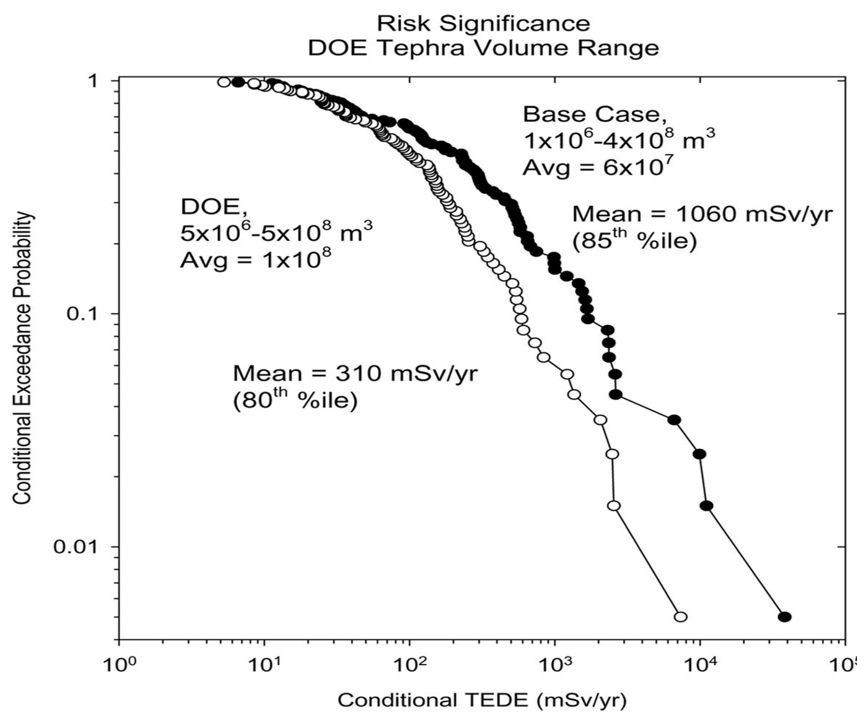

Figure 4-38. Eruptive Volume Sensitivity [U.S. Department of Energy (DOE), Total Effective Dose Equivalent (TEDE)]

analog volcanoes can range from approximately 1:1 to 6:1 (NRC, 1999); ratios of 1:1 to 2:1 were used in the NRC (1999) estimates for Yucca Mountain volcanoes. In addition to the presented analyses for areal concentration of entrained waste at 20 km [12 mi], the eruption volume also will affect the potential source-term for remobilization modeling. Although smaller tephra volumes can result in relatively higher initial waste concentrations at 20 km [12 mi], the amount of material available for subsequent remobilization to the 20-km [12-mi] location may be significantly less than for larger volume eruptions. Thus, larger volume eruptions, which may produce deposits with initially lower waste concentrations at 20 km [12 mi], could provide a larger amount of material that would be available for remobilization over time. Remobilization may result in the accumulation of tephra at the 20-km [12-mi] location that is equivalent to or greater than the thickness or concentration of the initial eruption deposit. Both the concentration of radioactive material in air and inhalation dose are sensitive to the deposit thickness and waste concentration in the deposit. As the deposit at the 20-km [12-mi] location evolves through time, remobilization processes could increase the probability-weighted expected annual dose at a time significantly (i.e., tens of years) after the initial eruption. However, current dose estimates, which assume a southerly wind direction, are dominated by the dose occurring in the year immediately following the eruption.

Remobilization of Ash Deposits: Medium Significance to Waste Isolation

After a potential eruption, contaminated ash could be deposited over hundreds to perhaps thousands of square kilometers (tens to perhaps hundreds of square miles). Through time, some of this ash can be eroded and transported by wind and water, with later deposition at or near the reasonably maximally exposed individual location. An influx of remobilized ash could affect the airborne mass loads at the reasonably maximally exposed individual location, depending on the rate of remobilization and dilution with existing soils.

<u>Discussion</u>

For a potential volcanic event within the repository footprint, most simulated eruptions would deposit some amount of volcanic ash on slopes with drainages that eventually feed into the reasonably maximally exposed individual location. Through time, wind and water will erode some fraction of the ash deposit and transport it southward down Fortymile Wash toward the reasonably maximally exposed individual location. Although tephra-fall deposits can erode within decades from areas with steep topographic gradients, deposits on relatively flat-lying areas are more resistant to erosion (e.g., Segerstrom, 1960). Sediment residence times in the confined channel of Fortymile Wash could be relatively short. Bed-load transport will move sediment down the main channel of the wash during periods of high water flow. In the reasonably maximally exposed individual area, the Fortymile Wash drainage morphology changes from a steep-sided channel to a broad, braided fan system. This location represents the point where significant long-term sediment deposition occurs within the Fortymile Wash drainage system. Sediment deposition and alluvial aggradation continues south into the Amargosa Desert and overlaps the reasonably maximally exposed individual location. Consequently, there is likely an initial period of enhanced tephra remobilization before sediment transport rates drop back to preeruption values.

The risk significance of remobilization is uncertain. Using a simple mass redistribution relationship, Hill and Connor (2000) suggested that remobilization could increase the net amount of ash at the general reasonably maximally exposed individual location by a factor of 2 to 10, relative to the original mass deposited by an eruption. This analysis also indicates that, if the wind is directed away from the reasonably maximally exposed individual during a simulated eruption (i.e., no deposition and, thus, no dose the year immediately following the event), the effect of ash remobilization could result in a dose at some time after the eruptive event at the reasonably maximally exposed individual location.

Current total system performance assessment calculations assume the potential eruption plume is always directed at the reasonably maximally exposed individual location, as a means to account for post-eruption remobilization. These calculations, however, assume that airborne mass loads above ash deposits decay after a potential eruption and that the ash deposit undergoes leaching and erosion with no influx of new material from remobilization. A relatively straightforward approach to evaluating potential risk significance of the remobilization issue is to examine the effect of sustaining airborne particle concentrations at post-eruption values. This effect can be simulated in the TPA Version 4.1j code by slowing the reduction in the airborne mass load with time (i.e., using larger values for the half-life of this process). Larger values represent slower decreases in airborne mass loads from the presumed influx of resuspendable ash through remobilization. Figure 4-39 shows the relative sensitivity of the decay function parameter in the average conditional dose for 100 realizations of an eruption occurring 1,000 years after repository closure. As a proxy for risk significance, the conditional doses for each year from 1,000 years to 2,000 years are individually weighted by a 10^{-7} annual probability of occurrence and summed. Compared to the risk proxy for a 14-year half-life, half-lives of 143 and 1,430 years result in increases by factors of approximately 2 and 5, respectively.

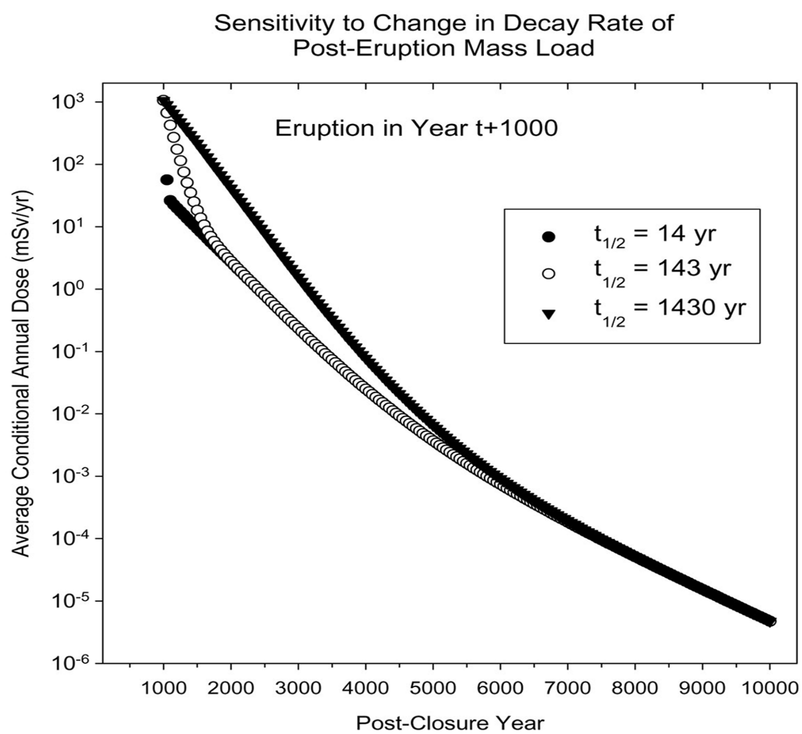

Figure 4-39. Relative Sensitivity for Assumptions of Airborne Mass-Load Decay Function [Time (t); half life ($t_{1/2}$)]

Uncertainties

Remobilization processes are not well-understood, and supporting data are sparse. Nevertheless, the airborne mass load for the years after a potential volcanic eruption is a highly sensitive parameter in total system performance assessment calculations, and uncertainties in this parameter strongly affect calculations of expected annual dose. However, tephra remobilized as a result of surface water is expected to mix with other soils, and transport of tephra by water is expected to result in reduced mass loading, relative to the air transport of tephra during the eruption.

Inhalation of Resuspended Volcanic Ash: High Significance to Waste Isolation

Inhalation of resuspended volcanic ash dominates the total dose for the igneous scenario. Thus, assumptions regarding the amount of fine ash particles in the air significantly influence the calculated dose. The thickness of the deposited ash layer and extent of potential mixing with the underlying soil affects the proportion of ash in the airborne particle load.

Discussion

The amount of fine ash particles resuspended above a deposit depends on the type and duration of surface-disturbing activities and on thickness of the deposit available for entrainment. Based on sensitivity studies using the NRC TPA Version 4.1 code, the parameter for the airborne particle concentration (mass load) above a fresh ash deposit was identified as the most influential to igneous activity dose (Mohanty, et al., 2002). The inhalation dose from a volcanic eruption increases or decreases according to the airborne mass load of waste. The decrease in total mass load after an eruption is assumed to follow an exponential decay in the model. The fraction of contaminated ash in the mass load also can be decreased by mixing ash with underlying uncontaminated soil. The amount of dilution depends on the thickness of the ash deposit and depth of the surface layer available for resuspension. In undisturbed areas, the resuspension layer is relatively thin {3 mm [0.1 in] in TPA Version 4.1j code}; activities such as agriculture disturb a thicker surface layer, and dilute the ash content of the mass load where the thickness of the disturbed layer exceeds that of the ash deposit. The DOE analyses using deeper surface layers {10 mm [0.4 in] and 150 mm [6 in]} lead to lower estimated annual doses that decrease with increasing surface layer thickness. To evaluate the sensitivity of the soil-mixing depth, thickness of the mixing zone was set to 150 mm [6 in], with all other parameters sampled at default values. Figure 4-40 shows that a factor of 50 increase in the soil mixing depth results in a factor of 12 reduction in average conditional dose.

Uncertainties

Further uncertainties exist for appropriate mass loads under different conditions local to the reasonably maximally exposed individual (e.g., extent and degree of disturbance, indoor or outdoor activities). Use of a soil-mixing zone may not be appropriate for reasonably maximally exposed individual that has only a minor component of agricultural habits and only limited surface-disturbing activities. Mass loads from semiarid regions may not accurately represent appropriate mass loads for the reasonably maximally exposed individual during the period of peak calculated risk (i.e., first 1,000 years postclosure), and many arid terrains may not have soil or vegetation conditions reasonably analogous to the reasonably maximally exposed individual location. The rate at which mass loading may decrease in the years following an eruption is also uncertain because of complex interrelationships between deposit erosion and

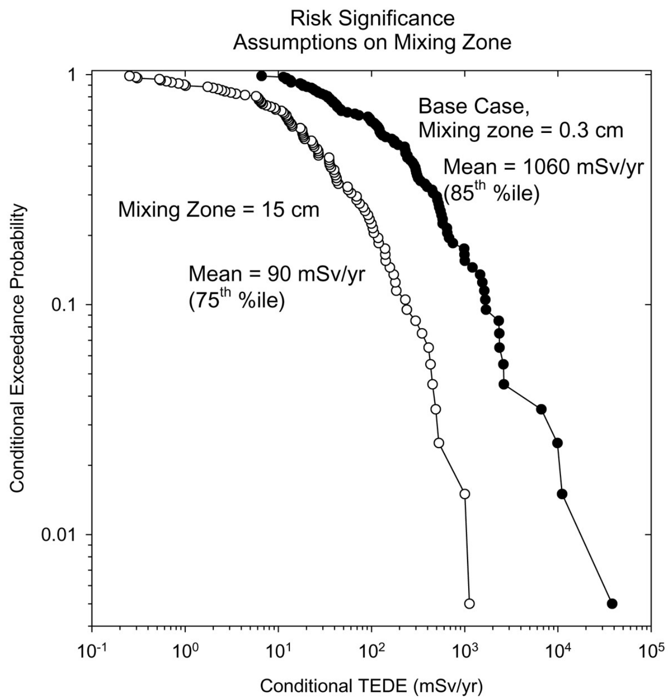

Figure 4-40. Sensitivity to Soil Mixing Depth [Total Effective Dose Equivalent (TEDE)]

the redistribution of inhalable particles. The upper bound of this uncertainty, however, does not appear to affect risk estimates significantly.

Wind Vectors During an Eruption: Medium Significance to Waste Isolation

Both wind speed and wind direction affect the transport of contaminated ash from the eruption source to the location of the reasonably maximally exposed individual. Wind speed has been shown to be an influential parameter in the sensitivity studies conducted with performance assessment codes. A distribution of wind speeds appropriate to model eruption columns 2 to 7 km [1.2 to 4.4 mi] high needs to be considered. The current total system performance assessment approach also fixes the wind direction toward the reasonably maximally exposed individual to simulate potential effects of post-eruption ash remobilization.

<u>Discussion</u>

In modeling potential volcanic eruptions, the TPA Version 4.1j code uses an exponential distribution of wind speeds with an average of 12 m/s [27 mi/hr], based on limited data. Further analysis of 28,000 measurements from 0 to 7 km [0 to 4.3 mi] altitude at the National Oceanic and Atmospheric Administration Desert Rock Airstrip suggest that a lognormal distribution with roughly the same median value is more appropriate. Calculations using this distribution give doses similar to those computed with TPA Version 4.1j code (Figure 4-41). Greater wind speeds yield proportionally greater dose, presumably because of thicker ash deposits at the reasonably maximally exposed individual site. In the DOE total-system performance assessment, setting the wind speed to the 95th percentile value [23 m/s [51 mi/hr]} gives roughly twice the dose as the basecase median wind speed of 11 m/s [25 mi/hr] (Figure 4-42).

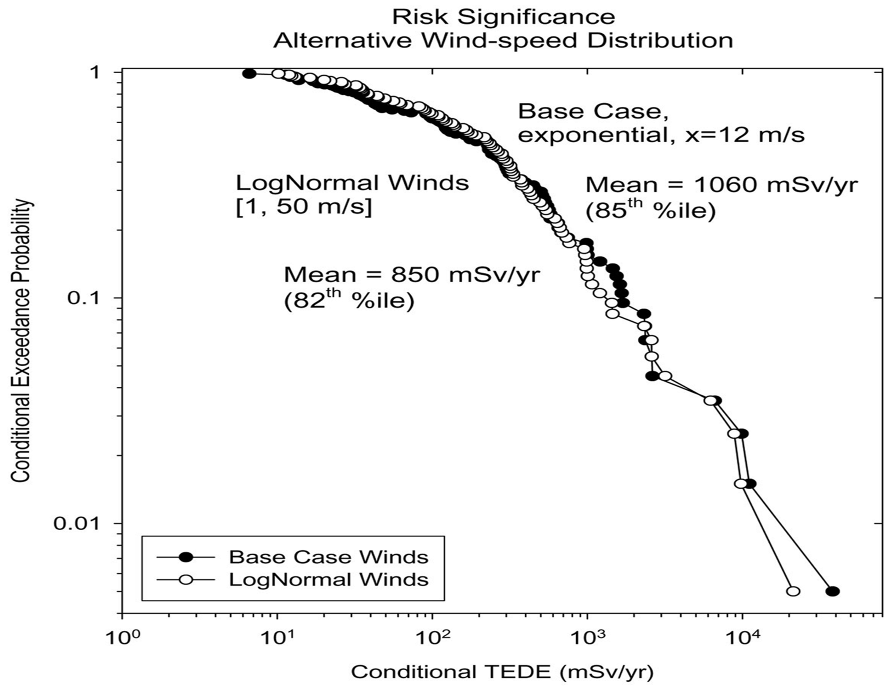

Figure 4-41. Variations in Conditional Annual Dose Using an Alternative Wind Speed Distribution [Total Effective Dose Equivalent (TEDE)]

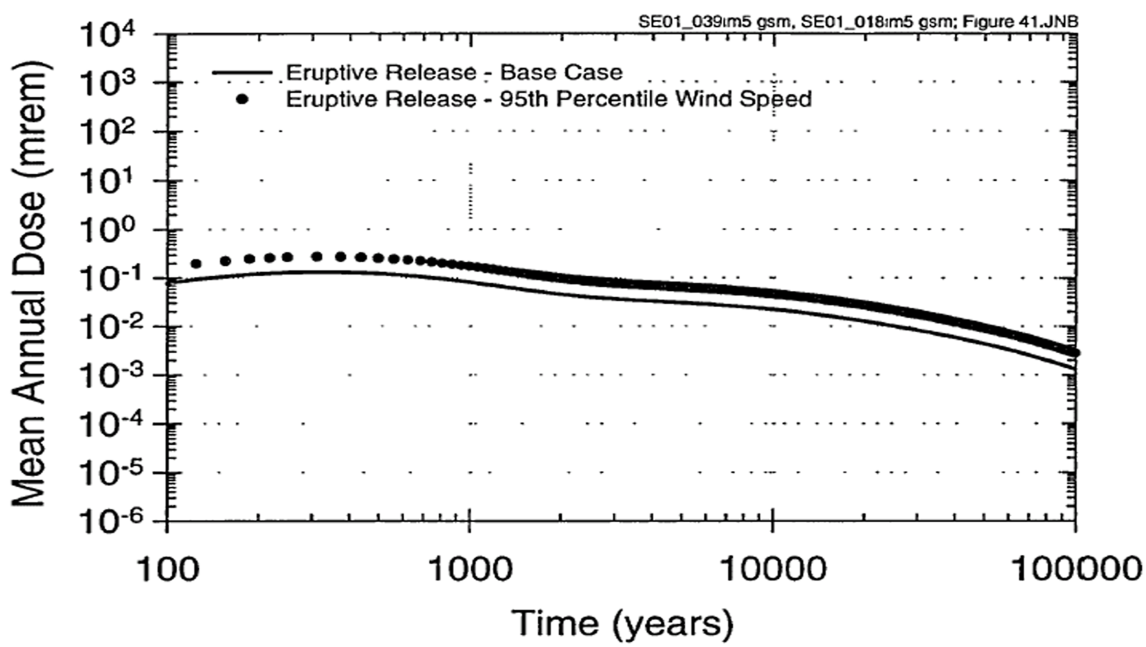

Figure 4-42. Sensitivity to Higher Wind Speed. (Bechtel SAIC Company, LLC, 2002. Note that Dose Estimates for Variations from the Basecase Do Not Represent Variations in Expected Risk Because the Probability of the Variation Is Not Considered) (1.0 mrem = 0.01 mSv)

Variations in wind direction during an eruption have not been fully analyzed. In both the DOE total system performance assessment and TPA Version 4.1j code, wind direction was fixed toward the reasonably maximally exposed individual site to compensate for the lack of any posteruption movement of contaminated ash. Clearly, if the wind direction is allowed to vary over a realistic range and the potential effects of ash remobilization are ignored, many total system performance assessment realizations will not deposit ash at the reasonably maximally exposed individual location. Scoping analyses presented in Hill and Connor (2000), however, indicated that long-term remobilization processes could result in ash deposits that exceed the thickness of primary volcanic deposits. Calculations that allow wind direction to vary without accounting for potentially significant effects of ash remobilization therefore provide limited insight on risk significance. Because of a lack of information on potential ash remobilization, a medium-risk significance is given to developing an appropriate representation of a realistic wind field above Yucca Mountain.

<u>Uncertainties</u>

The level of detail necessary to reasonably represent a complex wind field is uncertain, given the short transport distances being modeled relative to typical volcanic plume or particle modeling. Variations in deposit thickness on scales of less than a kilometer may be significant to dose calculations, if a realistic wind field and remobilization modeling are used. The time an erupted tephra particle remains at the top of the tephra plume is significantly longer than its rise time from the vent, or its depositional fallout time from the plume. Wind speeds are generally faster at higher altitudes; thus, realistic modeling must consider wind velocity profiles for rapid particle rise, extended lateral advection at the top of the plume, and depositional fallout through gravitational settling. Modeling assumptions (e.g., wind direction fixed in a southerly direction) and sensitivity analyses (e.g., variation of wind speed) have been used to understand the effects of many of these uncertainties.

4.3.12 Concentration of Radionuclides in Ground Water (DOSE1)

Risk Insights:	
Well-Pumping Model	Low Significance

4.3.12.1 Discussion of the Risk Insights

Well-Pumping Model: Low Significance to Waste Isolation

In the current well-pumping model, all radionuclides that enter the accessible environment are assumed to be captured in the volume of ground water projected to be withdrawn annually. This assumption limits the risk significance of modeling radionuclide concentrations in ground water.

<u>Discussion</u>

This abstraction relates to estimating the impacts of well pumping on the concentration of radionuclides in water. To limit speculation, this stylized calculation is described in 64 FR 8646 and its implementation is constrained by requirements at 10 CFR Part 63. The calculation involves dividing the estimate of the annual amount of radionuclides entering the accessible environment, that are captured by the pumping well (or wells), by the volume of water assumed to be pumped to the surface. The annual amount of radionuclides that enter the accessible environment is the result of the release and transport calculations in previously discussed model abstractions, so the risk insights for those abstractions will not be repeated here. The remaining parameters in the concentration calculation do not vary and, therefore, do not have any potential to increase or decrease the resulting concentration. For example, the annual water demand (i.e., pumping volume) is specified by regulation, at 10 CFR Part 63, as 3.7×10^6 m^3 [3,000 acre-ft], and all the radionuclides that enter the accessible environment are assumed to be captured in this specified water demand (a conservative assumption).

Uncertainties

No variation or uncertainty is generated in this abstraction because the regulation at 10 CFR Part 63 sets the pumping volume as 3.7×10^6 m^3 [3,000 acre-ft] and all radionuclides in the plume are conservatively assumed to be captured by the pumping well.

4.3.13 Redistribution of Radionuclides in Soil (DOSE2)

Risk Insights:	
Redistribution of Radionuclides in Soil	Low Significance

4.3.13.1 Discussion of the Risk Insights

Redistribution of Radionuclides in Soil: Low Significance to Waste Isolation

Ground water-based dose estimates are primarily influenced by the drinking water pathway, thereby limiting the importance of pathways related to radionuclides in soil. Igneous activity-based dose estimates are dominated by inhalation of radionuclides that have low mobility in soil, so leaching processes do not significantly affect estimated doses (low soil leaching leads to higher crop ingestion doses).

Discussion

The model abstraction for redistribution of radionuclides addresses the movement of radionuclides after deposition on the ground, either through surface application of ground water or settling of volcanic ash after an eruption. Redistribution affects the quantity and concentrations of radionuclides accessible to human receptors in the biosphere, and therefore, influences the dose estimates from radionuclides deposited on the ground. Redistribution can increase exposure if the transport processes involved move material closer to human intake pathways (e.g., resuspension to the breathing zone of an individual) or decrease exposure if transport is away from human exposure pathways (e.g., leaching to deep soil layers) or transport substantially dilutes initial radionuclide concentrations.

For ground water-based dose estimates, biosphere modeling results (Figure 4-43) show that, for the radionuclides that dominate the current dose estimates (Table 4-10), the drinking water pathway, which is not affected by soil redistribution processes, would contribute approximately

50 percent of the all-pathway dose estimates. Because only the remaining half of the all-pathway dose can be influenced by redistribution processes and this portion of the dose is dominated by the crop-ingestion pathway (Figure 4-43), the effect of redistribution processes on the all-pathway dose is limited. In the biosphere model, crops can become contaminated through root uptake or deposition of resuspended material. As a result, redistribution processes that alter the soil concentration on the soil surface and in the root zone of the crops can affect the crop-ingestion dose. These processes include leaching of contaminants to deeper soil layers away from roots, and buildup of contaminants from irrigation. Any potential impacts from contaminants leaching from the soil to the ground water are not addressed by the current model. Such secondary-use consequences are assumed to be lower than consequences attributed to initial reasonably maximally exposed individual use, because of the attenuating effects of dilution during transport.

To test the impact of soil leaching on dose-modeling results, the most variable parameter in the leaching calculation—the distribution coefficient—was input at the extremes of the range used in TPA Version 4.1d code biosphere calculations. The results (Figure 4-44) indicate that the greatest potential change in dose from variation in this parameter is about a factor of five. Because it is unlikely that the value of every distribution coefficient would be at the highest value of its known range, the effect on dose estimates from more realistic changes to this parameter is expected to be far less than the factor of five and is therefore considered of low-risk significance. This conclusion is further supported by the results of a system-level sensitivity analysis (Mohanty, et. al., 2002) that found no consistent significant influence on dose from soil-leaching parameters when all other total system model parameters were sampled.

DOE analyzed effects of soil buildup on biosphere dose-modeling results (CRWMS M&O, 2000) by modeling irrigation for time periods sufficient for soil concentrations to reach equilibrium (e.g., soil concentration remains constant with time). Results suggest the dose results for most radionuclides would be expected to change by 15 percent. Some radionuclides (i.e., americium, cesium, nickel, protactinium, plutonium, radium, strontium, thorium, and uranium) showed changes above this level (CRWMS M&O, 2000); however, these radionuclides are not contributing to the ground water-based dose estimates. In general, the properties that lead to buildup in soil (e.g., low mobility) also favor slow transport times in ground water.

For the igneous activity dose calculations, both NRC (Figure 4-45) and DOE (Bechtel SAIC Company, LLC, 2001) results indicate that the dose is dominated by inhalation of resuspended contaminated ash deposited from an eruption. Both NRC (Figure 4-46) and DOE (CRWMS M&O, 2000b, Figure 4.2-3) analyses indicate over 90 percent of the direct-release dose is from radioactive species of the elements americium and plutonium. The chemical properties of these elements lead to low leaching in soils, as indicated by the data and related information presented in Sheppard and Thibault (1990). A simple quantification of the low-leaching effect, using the environmental deposition and removal calculation described in the GENII v1.485 user manual (Napier, et al., 1988) and leaching factors calculated in the TPA Version 4.1 code for plutonium and americium, indicates that the annual surface soil concentration is reduced by less than 1 percent when leaching to deeper soil layers is considered.

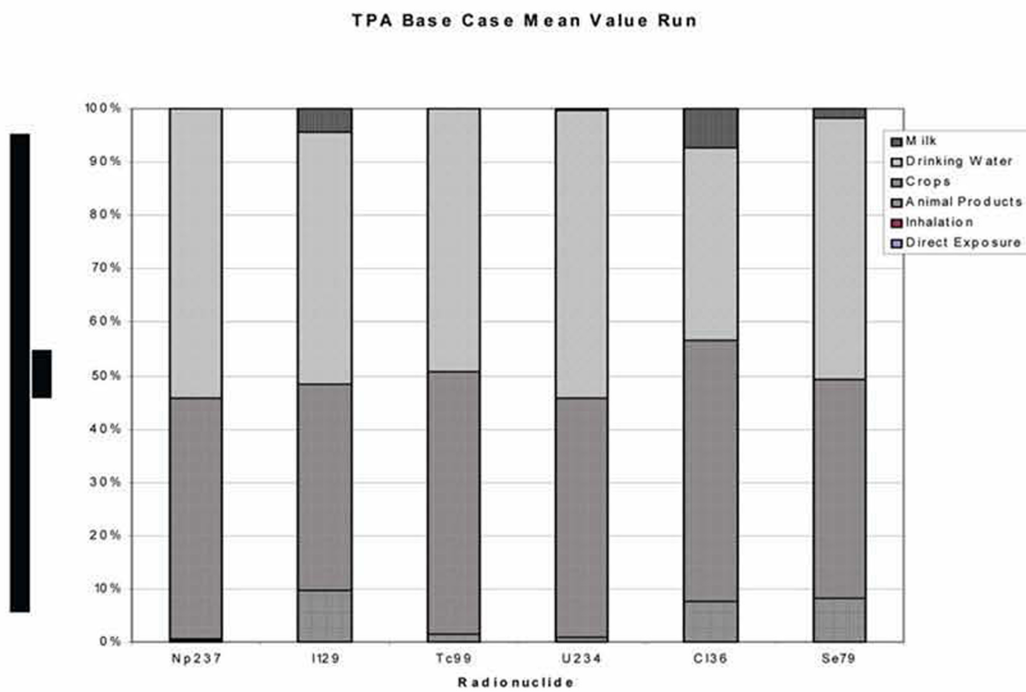

Figure 4-43. Ground Water Release Scenario: Exposure Pathway Contributions to Dose for Important Radionuclides (Using the TPA Version 4.1 Code)

Table 4-10. Primary Radionuclides Contributing to Peak Expected Dose (Mohanty, et al., 2002, Table 3-13)				
	10,000 Years		100,000 Years	
Radionuclide	**Mean Value Data Set (mSv/yr)**	**Multiple-Realization Data Set (mSv/yr)**	**Mean Value Data Set (mSv/yr)**	**Multiple-Realization Data Set (mSv/yr)**
Np-237	0	4.29×10^{-5}	3.69×10^{-2}	9.54×10^{-2}
I-129	1.30×10^{-4}	5.34×10^{-5}	3.90×10^{-4}	1.33×10^{-3}
Tc-99	2.15×10^{-4}	1.09×10^{-4}	6.17×10^{-4}	2.09×10^{-3}
U-234	0	1.77×10^{-9}	4.62×10^{-7}	6.80×10^{-5}
Cl-36	7.11×10^{-7}	2.64×10^{-7}	1.35×10^{-6}	5.10×10^{-6}
Se-79	0	3.74×10^{-8}	9.31×10^{-6}	1.14×10^{-5}

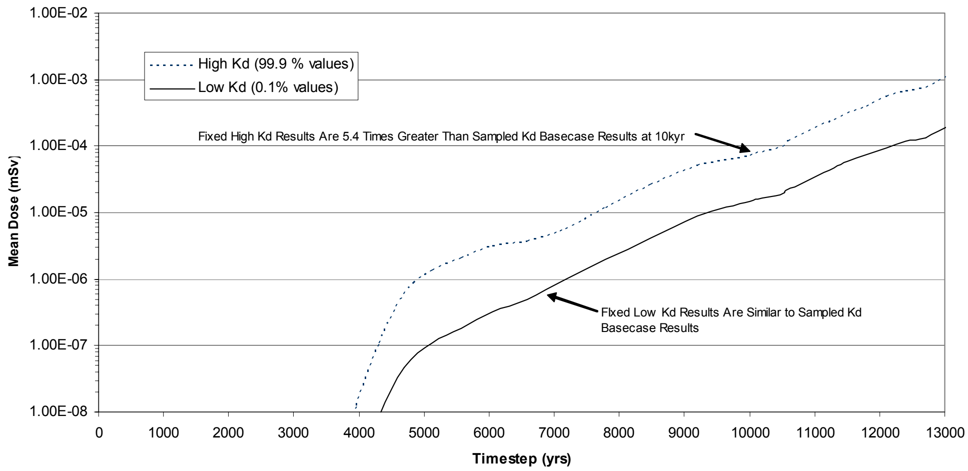

Figure 4-44. Comparison of Dose Curves from Basecase and High and Low Perturbations of Soil Distribution Coefficients (Kd) Using the TPA Version 4.1d Code

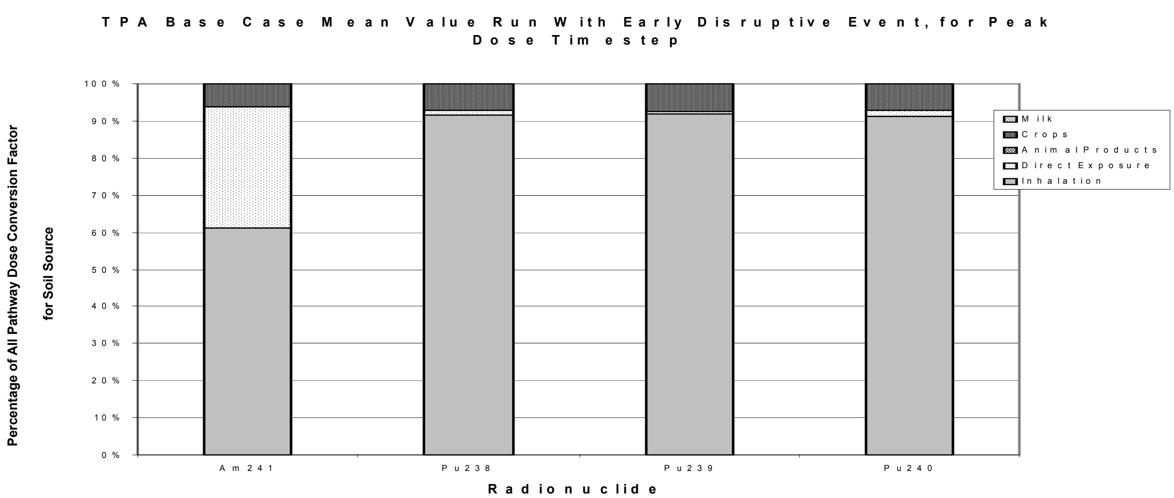

Figure 4-45. Igneous Activity Release Scenario: Exposure Pathway Contributions for Important Radionuclides (Using the TPA Version 4.1 Code) (Am-241, Pu-238, Pu-239, Pu-240)

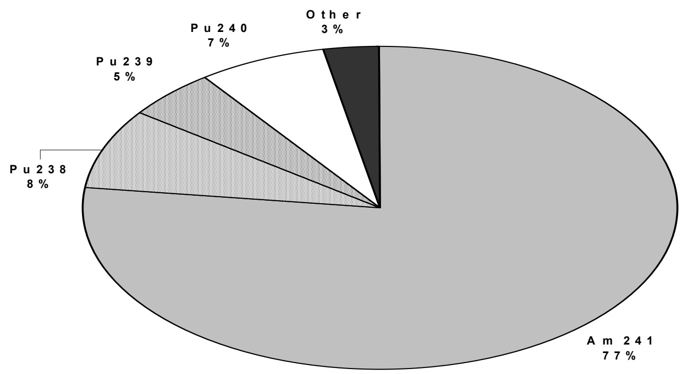

Figure 4-46. Key Radionuclides for Igneous Activity Disruptive Event Dose (Using the TPA Version 4.1 Code) (Am-241, Pu-238, Pu-239, and Pu-240)

<u>Uncertainties</u>

For the ground water-release biosphere calculations, leaching of radionuclides in soils is an uncertain process. However, the aforementioned analyses suggest the magnitude of the impacts of this uncertainty on dose is low when evaluated in the context of other uncertainties in the performance assessment (i.e., the variation in the biosphere calculations is small compared to the rest of the performance assessment). For the igneous release, the uncertainty in the leaching behavior is less important because radionuclides that dominate the dose have low mobility in soils. Other potential redistribution processes (e.g., surface remobilization) are somewhat uncertain.

4.3.14 Biosphere Characteristics (DOSE3)

Risk Insights:	
Characterization of the Biosphere	Low Significance

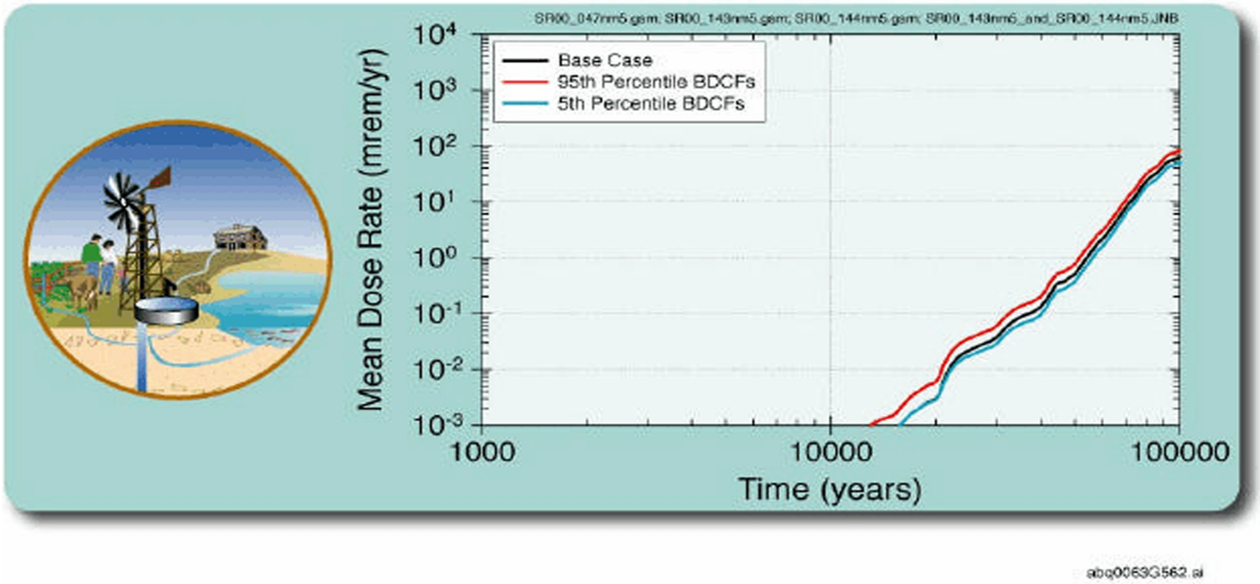

Figure 4-47. Sensitivity to Biosphere Dose Conversion Factors. (From CRWMS M&O, Page F5-38) (1.0 mrem/yr = 0.01 mSv/yr)

4.3.14.1 Discussion of the Risk Insights

Characterization of the Biosphere: Low Significance to Waste Isolation

The regulation at 10 CFR Part 63 specifies mean values to be used for many important biosphere parameters, thereby limiting the effect of biosphere modeling assumptions and parameters on total system risk estimates.

<u>Discussion</u>

NRC regulations at 10 CFR Part 63 specify the use of mean values for behavioral input parameters (i.e., diet and living style) such as consumption rates and exposure times, which reduces the range of variation in the ground water-release biosphere model abstraction calculations (NRC, 2002; page 3.3.14-11). The DOE evaluation of the impact of the biosphere modeling variation on estimated dose results is shown in Figure 4.47.

<u>Uncertainties</u>

As noted in the discussion, the uncertainties in the biosphere calculations are limited by requirements at 10 CFR Part 63. Based on the available parameter information used for the ground-water-release biosphere dose calculations, the staff does not expect that a significant increase in the uncertainty propagated in the biosphere calculations would occur from additional information. For igneous activity biosphere dose calculations, the modeling of features and processes that lead to resuspension of contaminated volcanic ash (e.g., the mass-loading factor) at the location of the reasonably maximally exposed individual is both highly uncertain and important to dose results. Although conceptually this is a biosphere abstraction issue, it is also addressed in the igneous disruptive event abstraction in Section 4.3.11 and is not considered further in ranking the significance to waste isolation of the biosphere.